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Technical Note

Catalytic Solutions to the IMO Challenge: The Resid FCC Alternative

Overview

The International Maritime Organization (IMO) regulations regarding bunker fuels, to take effect in 2020, present one of the biggest challenges in the refining industry's history. Per these regulations, the limit for sulfur content in marine fuels will decrease from 3.5 to 0.5 wt%.

According to multiple market sources, the decreased limit will affect the production and trading of residual bunker fuel, changing the structure of refineries' fuel output by severely limiting the outlet for high sulfur fuel oil.

Despite uncertainties regarding the actions to be taken by the shipping companies to comply with the upcoming IMO regulation, several solutions are available for refiners to lower the sulfur content of their fuel output. Implementation of such solutions is usually the product of deep techno-economic analysis, depending on the particular situation of each refinery.

Certain process technologies can convert or desulfurize the residues that are the main raw material used to produce residual bunker fuels. Some common process technologies are coking, resid fluid catalytic cracking (resid FCC), resid hydrodesulfurization (RDS) and resid hydrocracking (RHC).

This article focuses on the resid FCC process as an attractive solution for refiners to overcome the IMO challenge. Refiners operating FCC units can provide flexibility by implementing the following alternatives:

- Diverting part or all of the residual stocks from the fuel oil pool to the FCC feed;
- Increasing the portion of residual feed processed in the FCC unit;
- Reducing residue, i.e. slurry oil, generation from the FCC itself.

Since resid FCC units require catalysts to convert residual feeds into products, this article also highlights the development of novel catalyst technologies oriented to process residual feeds and/or reduce slurry oil production.

The IMO Regulation

The IMO oversees the regulation of marine transportation activities, with a focus on reducing environmental impact.

To reduce SOx emissions from ships, IMO has made the decision to limit the legal sulfur content in marine fuels to 0.5 wt% by 1st of January 2020 [(1)]. This limit is particularly challenging for refineries that rely on heavy bunker fuel as an outlet for residual products such as vacuum residue, solvent deasphalting (SDA) pitch, visbroken oil, or FCC slurry, due to the extremely high sulfur content of these streams for most crude oil slates.

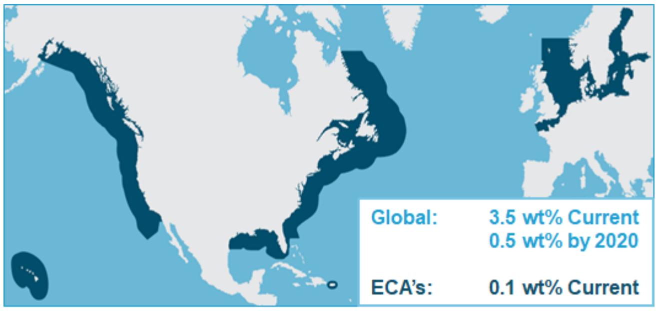


Figure 1: IMO regulations for sulfur content in marine fuels *[2]*

Implementation of the IMO regulations will result in drastically changing markets and create short-term opportunities demanding refiner flexibility to capture value[3]. Thus, it is imperative that refiners take advantage of the most effective option available to them.

Resid Upgrading Routes

Fortunately, process technology provides several solutions to this challenge. These include (1) hydrotreatment of the residual products and (2) conversion of these streams into lighter molecules, which can then be directed toward transportation fuels such as diesel or gasoline, or even petrochemical building blocks such as propylene or ethylene.

Therefore, two general options are available for refiners to upgrade the residual streams already going to bunker fuel oil: the **treatment** route and the **conversion** route, the latter of which is more conducive to increasing refiner competitiveness.

Treatment Route:

The refiner can produce marine/bunker fuels in compliance with IMO specifications, usually by hydrodesulfurization. Using this approach, the refinery product slate is very similar. The resulting fuel oil sulfur content is compliant, and the fuel can be traded in line with regulations.

This option allows the refiner to meet IMO regulations, but it does not yield a step-wise increase in the product profit margins.

Conversion Route:

Alternatively, the refiner can convert the residual streams into lighter molecules, which are then either used to manufacture transportation fuels such as gasoline or diesel, or converted into petrochemical building blocks such as propylene or ethylene. Due to the wide scope of results offered by conversion, this route has the potential to fundamentally change the refinery product slate by generating higher priced products. Thus, conversion represents an opportunity for significant improvement in competitiveness due to higher refining margins.

Table 1 provides a high-level comparison of the various options available to refiners under the traditional classification of catalytic/non-catalytic technologies and approaches based on hydrogen addition/carbon rejection.

Table 1: High-level comparison of common resid conversion technologies

Type	Process	Pros	Cons
Non-catalytic/ Carbon Rejection	Deasphalting (technically a non-conversion technology)	Less capex	Asphaltic pitch. Further processing generally needed.
	Visbreaking	Less capex	High sulfur fuel oil. Further processing needed.
	Coking	Medium capex	Product hydrotreatment needed. Pet-coke difficult to sell/trade.
Catalytic/ H_2 Addition	Ebullated Bed Residue Hydrocracking	High-value products	High capex. Residue difficult to sell/dispose.
	Slurry Residue Hydrocracking	High-value products	High capex. Still not common technology. Residue difficult to sell/dispose.
Catalytic/ Carbon Rejection	**Resid Fluid Catalytic Cracking (RFCC)**	**High-value products Sellable/stable residue (Slurry oil)**	May need pre-treatment (depending on crude quality).

Refiners must decide which process is best suited to their needs. Due to the financial implications of these investments, the best solution depends on the individual situation according to local and global market trends, product yield estimation, project costs, and the overall impact on the specific refining economy.

Generally, the more high-value products are obtained, the more capex is needed to upgrade the residual streams. Also, when higher conversion is attained, usually the more challenging aspect is to discard the final residue, implying that the operational impact of the selected process technology should also be part of the decision-making process.

Improving Refiner Competitiveness via Resid Upgrading

If the refiner converts residues to improve competitiveness, this means that instead of producing heavy fuel oil, the product slate would shift to produce high-value fuels such as diesel or gasoline, or even petrochemical stocks, as previously described.

However, even though most conversion technologies convert the bulk of the residual streams (60-90%, depending on the feed quality and the technology), there will always be a non-converted portion that will eventually be more difficult to deal with than the original residual feed, albeit in lower quantities.

Due to market conditions, trading restrictions, or stability concerns when blended with other hydrocarbon stocks, the final residue is difficult to offload. These unconverted materials vary by technology as follows: pet-coke from coking, unconverted residue from resid hydrocracking, and slurry oil from resid FCC.

Assuming unconverted material needs to be sold as fuel oil, as carbon, or stored indefinitely (with no immediate product outlet), resid FCC technology offers the opportunity to generate saleable product out of the final slurry oil residue, since the slurry can be used as a raw material in the production of carbon black or further processed in delayed coking units to produce high-quality anode coke.

In addition, FCC slurry oil can be easily blended with no stability concerns with other hydrocarbon stocks to produce low sulfur fuel oil (LSFO), which complies with IMO regulations. The rest of the products of a resid FCC typically need to be hydrotreated to produce clean automotive fuels. Propylene is commonly purified to petrochemical grade, while ethane/ethylene is usually sent to steam cracking facilities for further processing. Nevertheless, it should be reiterated that a conclusive resid upgrading solution depends on the refining economy impact.

Table 2: Resid FCC products and their potential uses

Product	Potential uses
Dry gas	▪ Petrochemical building blocks (ethylene) ▪ H_2 recovery (feed for PSA or membrane separation)
LPG (C_3s)	▪ Petrochemical building blocks (propylene)
LPG (C_4s)	▪ Alkylate (high-octane component for gasoline production) precursors
Naphtha	▪ High-octane blending component for gasoline ▪ Further cracking to petrochemical building blocks (ethylene and propylene)
LCO	▪ Diesel fuel component (hydrotreatment is generally needed)
Slurry	▪ Raw material for carbon black ▪ Low sulfur fuel oil component (after blending with low sulfur components) with no stability issues, unlike unconverted streams from other technologies ▪ Raw material for anode coke

The Contribution of FCC Catalyst Technology

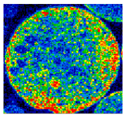
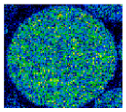
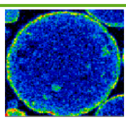
As the resid FCC process is catalytic, a catalyst is required for conversion and selectivity of products, whether the target is to produce high-quality fuels, petrochemical building blocks, or intermediate streams, as described in Table 2.

Resid FCC catalyst suppliers contribute to the enhancement of refiners' competitiveness by providing catalytic solutions to maximize conversion of residues to the targeted high-value products or intermediate streams. Contemporary catalytic technology platforms offer refiners solutions to either maximize the residual streams' processing capacity or minimize slurry oil production.

Some features of these catalytic technologies include the following (see Table 3):

- High tolerance to metals, especially nickel, vanadium, sodium, and iron
- Low coke production
- High bottoms upgrading properties (conversion of slurry to LCO and/or gasoline)

Table 3: Metal contamination mechanisms and solutions for high metals tolerance in a resid FCC catalyst[4]

Metal	Distribution	Effect	Metal Mobility	Passivation Technologies
Ni	 On edges of particle	Dehydrogenation: Increases H_2 and coke	Low	Specialty Alumina **Boron-based Technology** Avoid introduction of Cl into FCCU
V	 Throughout particle	Zeolite destruction Activity reduction Dehydrogenation: Increases H_2 and coke	High	Vanadium passivator e.g. **Valor™** Low Na content catalyst High zeolite content
Fe	 On edges of particle	Added Fe blocks catalyst surface, hindering access to catalyst sites Mild dehydrogenation, CO promotion, increases SOx	Low	Catalyst with high porosity & engineered pore architecture

The following cases demonstrate how various catalytic solutions can be used successfully in combination with versatile resid FCC process technologies. These cases support the maximum conversion of refining residues into high-value products as a means to overcome IMO challenges while providing higher competitiveness to the refiner.

Case 1. Atmospheric residue unit targeting maximum conversion to gasoline and propylene.

This unit, processing straight run atmospheric residue, used BASF's Flex-Tec™ catalyst to achieve their targeted maximization of gasoline. A moderate ZSM-5 addition increased their propylene output.

Table 4: Feed properties and product yields (Case 1)

Feed Properties		Product Yields (wt%)	
Type	Atmospheric residue	Dry gas + H_2S	5.6
Capacity	35 kBPD	LPG / C_3's	17.3 / 7.0 (*)
ConCarbon	4.5 wt%	Naphtha	50.0
Ni + V/4	10 ppm	LCO	10.1
V+Na	12 ppm	HCO + Slurry	8.7
Catalyst	Flex-Tec	Coke	8.3

(*) Low to medium ZSM-5 addition

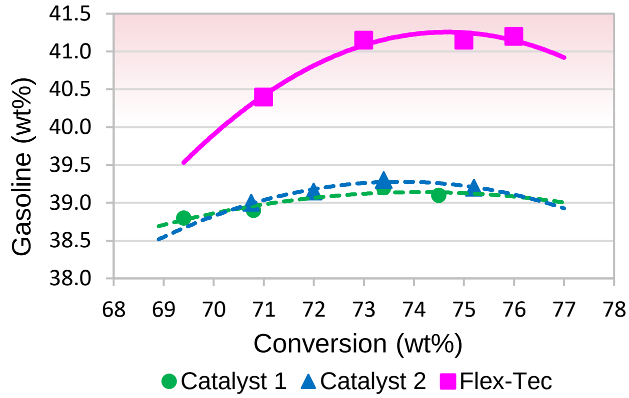


Figure 2: Improved gasoline selectivity with Flex-Tec

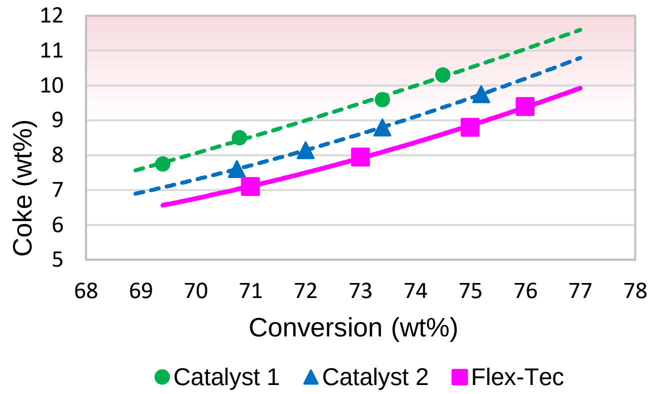


Figure 3: Decreased coke selectivity with Flex-Tec

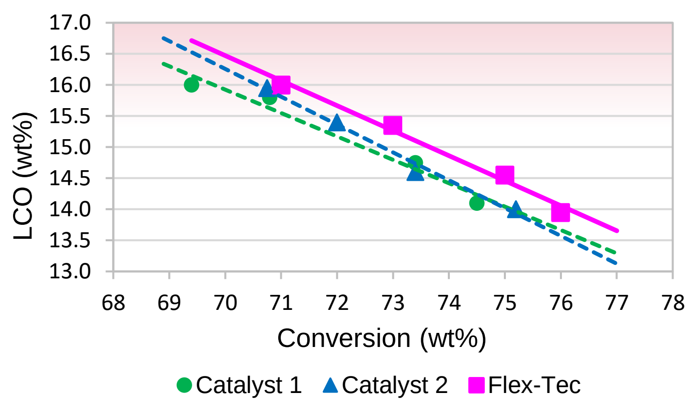


Figure 4: Increased LCO production with Flex-Tec

In this unit, Flex-Tec optimized gasoline and coke selectivity compared with two previous catalysts (Figures 2 and 3, respectively) and allowed higher middle distillate production (LCO) at the expense of slurry, hence minimizing yield of residual slurry oil (Figure 4).

Case 2. Atmospheric residue unit targeting maximum conversion to gasoline, high octane, moderate propylene, and higher ConCarbon in feed.

This unit, also processing straight run atmospheric residue, targeted the maximization of gasoline with moderate propylene yields. In this case, since high nickel content presented a unique challenge, the catalyst Fortress^{TM} NXT was selected to take advantage of its specialty alumina to passivate nickel. The technology minimizes nickel's effect on hydrogen and coke production. Indeed, for this unit, the dry gas production is relatively low when compared with other units with similar feeds but different catalysts. Again, low to medium ZSM-5 addition was added to support propylene production while boosting gasoline octane.

Table 5: Feed properties and product yields (Case 2)

Feed Properties		Product Yields (wt%)	
Type	Atmospheric residue	Dry gas + H_2S	3.3
Capacity	70 kBPD	LPG / C_3's	18.0 / 6.6 (*)
ConCarbon	7.0-7.5 wt%	Naphtha	49.9
Ni + V/4	25 ppm	LCO	8.7
V+Na	3 ppm	HCO + Slurry	10.4
Catalyst	Fortress NXT	Coke	9.6

(*) Low to medium ZSM-5 addition

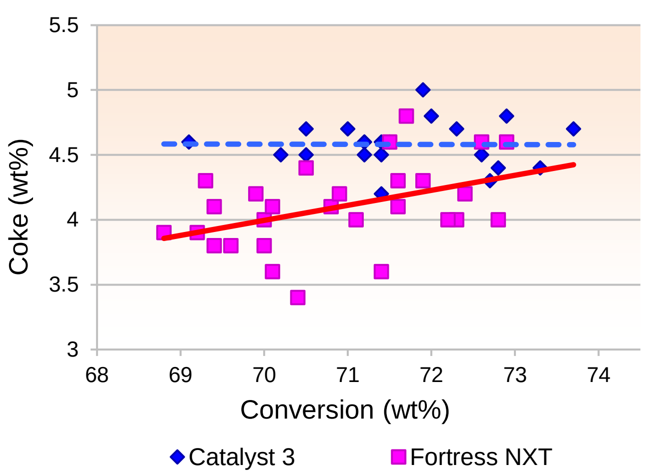


Figure 5: Decreased coke selectivity with Fortress NXT

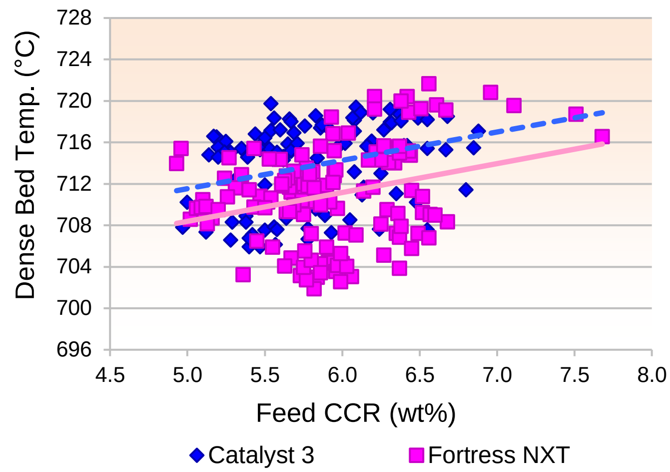


Figure 6: Decreased regeneration temperature with Fortress NXT

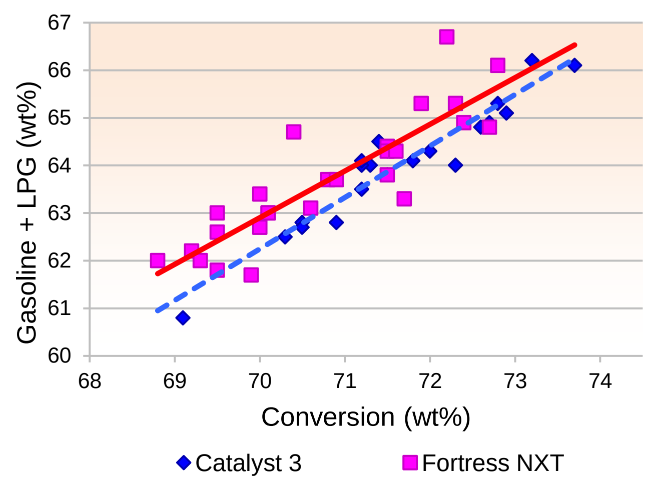


Figure 7: Increased gasoline + LPG selectivity with Fortress NXT

For this unit, Fortress NXT improved coke selectivity, which is a crucial factor for a unit processing a feed with 7.0 wt% ConCarbon. Indeed, thanks to the excellent coke selectivity of Fortress NXT, the unit was able to increase the ConCarbon content in feed to 7.5 wt%, allowing more distillate production in the crude unit.

Another effect of the improved coke selectivity of Fortress NXT is decreased regenerator temperature, allowing for a higher Cat/Oil ratio and hence higher conversion, which as demonstrated by this study, results in an improved gasoline + LPG yield, even when processing a heavier feed.

Conclusions

Stricter IMO regulations will be enforced by 2020, drastically lowering the allowable limit of sulfur content in marine fuels. The resid FCC process technology is a desirable option for refiners to overcome the challenge presented by the upcoming regulations.

Since in the resid FCC process, the production of residual low value byproducts (slurry oil) is minimal to zero, the refining margin is maximized, even under a highly constrained market.

BASF technology provides a wide range of catalytic solutions to process many types of residues. BASF's FCC catalysts and catalytic technology platforms are high-performance options for resid FCC units in their challenge to process heavy residues, minimizing slurry and heavy fuel oil production with superior coke selectivity, with the ultimate focus on improving refining margins despite a challenging market.

References

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5. This technical note is based on the following presentation: Salgado, H., Clough-Mastry, M., Riva, S., Gan, W.S. and Apoorv, A. *Catalytic solutions to overcome IMO challenges*. Middle East Refining Technology Conference (MERTC), Bahrain. January 2019.

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